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IDENTIFICATION OF *CALANCO*, A BADLAND LANDFORM IN THE NORTHERN APENNINES, ITALY

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ABSTRACT

Calanco (plural, *calanchi*) is a term widely used in the northern Apennines, Italy, to define a type of badland formed in clayey bedrock. However, no precise geomorphological definition of *calanco* has been established and a variety of map symbols are used to indicate the presence of *calanco* landforms. With the aim of developing an improved approach to identifying *calanchi*, a group of experienced surveyors identified 24 catchments with *calanco* characteristics among 67 catchments located between Bologna and Faenza in the northern Apennines. The morphology of each catchment was classified using traditional quantitative geomorphic approaches including fieldwork, map interpretation, hypsometric curve construction and computation of the annual sediment yield. Consideration of the parameters produced by these approaches indicated that none was capable of representing the presence of *calanchi* unequivocally and the basins were grouped into five classes on the basis of number and type of *calanco* criteria that they met. A characteristic of *calanchi* that is evident on topographic maps is crenulation of the contour lines and in this study a new topographic parameter was developed to represent the degree of contour crenulation. This parameter, *LO/LF*, is defined as the ratio of the actual length of a contour line (*LO*) to the length of the same line smoothed by an algorithm based on a moving average (*LF*). Calculated values of *LO/LF* ranged from 1·05 to 1·38. To test whether high values of the contour crenulation parameter were associated with *calanchi, LO/LF* values were added to other criteria for the five classes of catchment. Class 1 catchments, consisting of 14 of the 24 *calanchi* catchments identified in the field, displayed all of the criteria defining *calanchi*, and were characterized by the highest values of *LO/LF* (mean value $1{\cdot}27 \pm 0{\cdot}15$). It is proposed, therefore, that the contour crenulation ratio (*LO/LF*) may be useful in identifying the *calanco* landform. Copyright © 2000 John Wiley & Sons, Ltd.

KEY WORDS: *calanco*; badland; hypsometric curve; sediment yield; contour crenulation; Apennines

INTRODUCTION

Calanco (plural, *calanchi*) is a dialectic term originating from the Emilia-Romagna region of northern Italy, used to describe small catchments that are undergoing accelerated erosion (Figures 1 and 2). Probably, it derives from the latin word *chalare*, to slide (Treccani, 1949; Cortellazzo and Zolli, 1979). *Calanco* landforms have become widespread throughout the major valleys and northeast foothills of the northern Apennines (Figure 3) and use of the term now extends to the entire Apennines region. The rapidity of landscape evolution in *calanco* landscapes in the Emilia-Romagna region is evident when historical maps are compared (Figure 4). *Calanchi* are both important expressions of natural landscape to be preserved by law, and vulnerable areas where, for example, waste disposal is forbidden (RER, 1993; Provincia di Bologna, unpublished data, 1994).

The Italian geographical and geological literature contains frequent references to *calanchi* in connection with a variety of badlands and associated with the terms *biancane* and *balze* (Rodolfi, 1997). Many qualitative definitions of *calanco* may be found in the literature, citing as characteristic features ridges, gullies, abrupt slopes and a well developed drainage network (Stefanini, 1914; Marinelli, 1915; Castiglioni, 1933, 1935; Losacco, 1933; Passerini, 1937; Gortani, 1937, 1959; Vittorini, 1971, 1977, 1981; Lulli, 1974; Guasparri, 1978; Castiglioni, 1979; Sdao *et al.*, 1984; Rodolfi, 1991, 1997; Torri *et al.*, 1994; Busoni *et al.*,

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Figure 1. Typical *calanco* landscape on Pliocene clayey bedrock in the northern Apennines (Emilia-Romagna, Italy)

Figure 2. Two hydrographic basins featuring *calanco* characteristics (Zena valley, Bologna). Note the earth dams used to modify the longitudinal profile in order to reduce erosion

1995). For example, Castiglioni (1979, p. 118) defines *calanco* as 'a group of minor valleys characterised by steep hillslopes, without vegetation, in rapid evolution on clayey bedrock'.

Calanco landforms are represented by a range of symbols on topographic and large-scale planning maps (Figure 5). The symbols refer to open polygons (symbols 1, 3, 4, 6, and 7 in Figure 5) or closed polygons (symbols 2 and 5 in Figure 5). The first category defines only the highest boundary of headwall retreat, leaving the lower boundary undetermined. The second category is more consistent with the natural terrain of *calanco* landscapes which feature small-scale hydrographic cells, and is perhaps closer to the common definition of the *calanco* landform. While traditional geomorphic analyses may be used broadly to classify *calanco* features, the availability of modern, high accuracy maps raises the possibility of improving on these qualitative definitions and symbols by developing a topographic parameter that can use the characteristics of

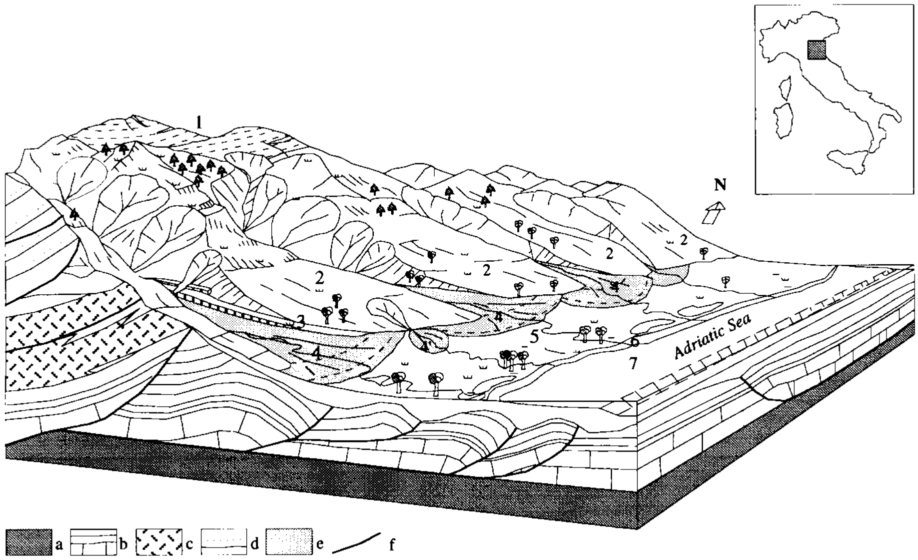


Figure 3. Structure and morphology of the northern Apennines. Structure: a, metamorphic basement; b, Triassic–Pliocene ‘autoctonous’ Romagna sequence; c, chaotic complex; d, Mesozoic–Lower Miocene ‘Tuscan sedimentary sequence’; e, Pleistocene sediments; f, thrust fault. Morphological units: 1, mountain/hilly belt; 2, major triangular elements; 3, terraced alluvial deposits; 4, major alluvial fans, locally covered by minor and more recent fans; 5, the Po Plain; 6, beaches, delta fans and marine terraces; 7, marine shore and shelf facies of the Adriatic Sea (after Farabegoli and Forti, 1997)

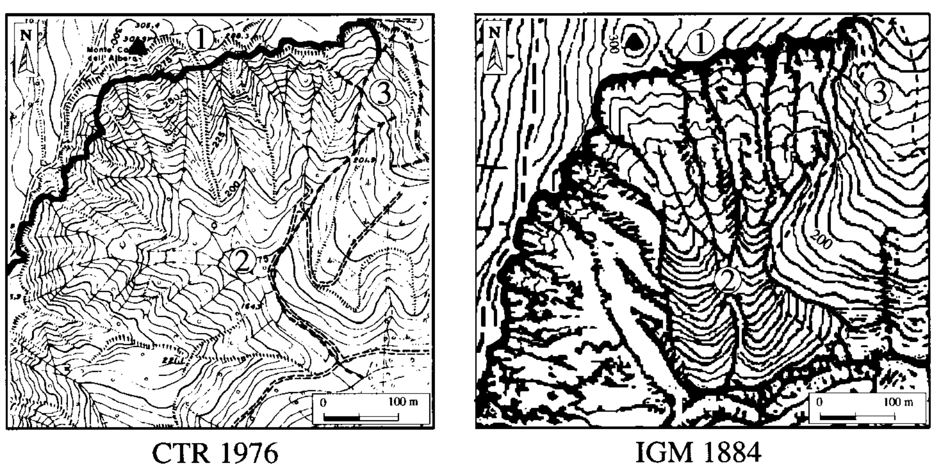


Figure 4. Comparison between recent map (CTR, 1976) and a historical map (IGM, 1884) to highlight erosion in the Rio Monazzano Basin (Mo4). Note: (1) cliff retreat 30 m northwards; (2) two axial mudflows that have been mobilized; (3) development of a new second-order basin along the previous eastern margin of the catchment

calanco landscapes to discriminate them from other landforms. To this end, this paper reports the results of attempts to define an easily calculable parameter to identify terrain typical of the *calanco* landform.

TRADITIONAL MORPHOLOGICAL ANALYSES OF HYDROGRAPHIC BASINS

Traditionally, processes and landforms of hydrographic basins are evaluated by hypsometric analysis (Strahler, 1952, 1957) and quantitative morphometric analysis (Ciccacci *et al.*, 1981, 1988, 1992). The

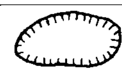
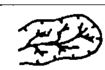
1		Panizza, 1972
2		Amadesi & Vianello, 1978
3		Cusimano *et al.*, 1978
4		Guasparri, 1978
5		R.E.R., 1981
6		R.E.R., 1987
7		G.N.G.F.G., 1993

Figure 5. Examples of symbols used to indicate *calanco* landforms on topographic and geomorphic maps

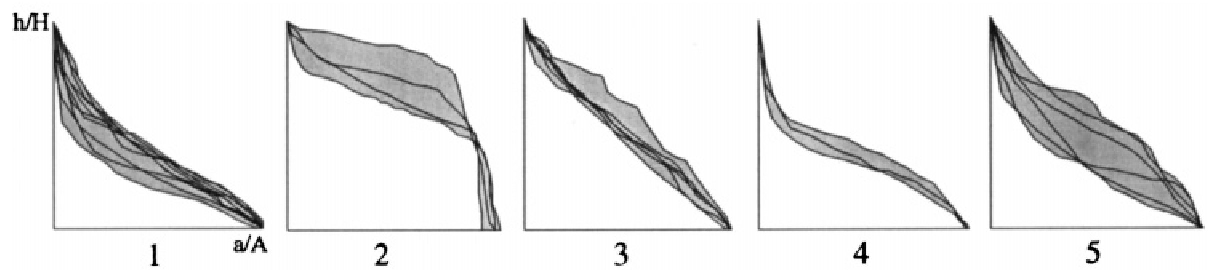


Figure 6. Five families of hypsometric curve associated with basins formed by different geomorphic processes: 1, rill and *calanco*-type erosion; 2, fluvial erosion; 3, hillslope processes and fluvial erosion; 4, sheet erosion; 5, complex erosion. Axes are defined by: ordinate, h/H = relative elevation/maximum elevation; abscissa, a/A = upsole area/cumulative area (after Ciccacci *et al.*, 1988)

starting point of a study attempting to define *calanco* should, therefore, be the application of these methods to identify basins featuring *calanco* characteristics.

Hypsometric analysis

The hypsometric method of Strahler (1952, 1957) was applied to 64 Apennine basins to evaluate the main geomorphic systems (Ciccacci *et al.*, 1988). Five families of hypsometric curve were identified and the envelopes of these curves (Figure 6) were used as visual comparitors to characterize the geomorphic systems operating in each basin.

Calanco landscapes generally fell into Family 1 in Figure 6, being characterized by concave-upward hypsometric curves and low values of the hypsometric integral. In some cases, however, the association between *calanchi* and Family 1 failed. For example, the hypsometric curve of the Mo7 basin (Monazzano creek, Zena valley) belongs to Family 1, although *calanchi* cover only 16 per cent of the basin area (Figure 7).

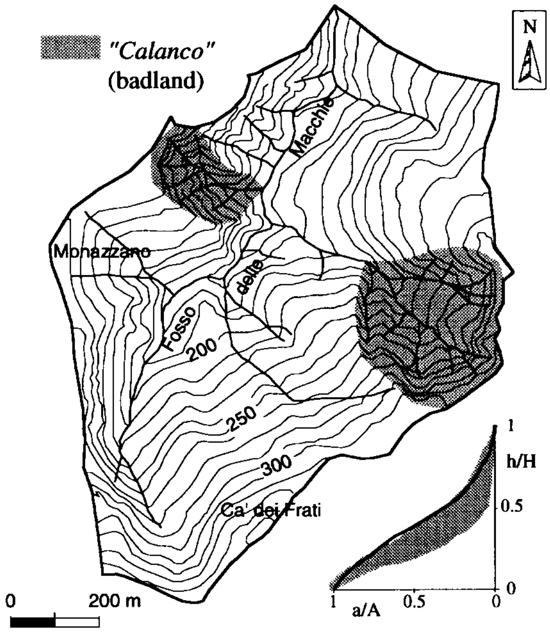


Figure 7. Hypsometric curve for basin Mo7. This belongs to Family 1, but only 16 per cent of the basin area is covered by *calanchi*

On the basis of the analysis performed here, it is clear that the hyspometric curve alone cannot be used to identify whether *calanco* landscapes make up a significant proportion of a catchment. It may, however, be useful when used in conjunction with other relevant criteria.

Morphometric analysis

Ciccacci *et al.* (1981) collected annual suspended sediment yield (*Tu*) data, expressed in tonnes per square kilometre per year (t km^{-2} a^{-1}), for gauging stations in 14 major catchments in the Apennines and developed four different empirical relationships between the sediment yield and the morphometric characteristics of the basins. The most widely applicable of these relationships is:

$$\log Tu = 0 \cdot 33479 \log D + 0 \cdot 15733 \Delta a + 1 \cdot 32888 \quad (1)$$

where D = drainage density and Δa = hierarchical anomaly index.

In their study, morphometric parameters were estimated from 1:25 000 topographic IGM (Italian Geographical Military Institute) maps. Eight categories of suspended sediment yield (*Tu*) were used to classify the intensity of geomorphic processes operating in the basins. Of particular relevance to the present study, Ciccacci *et al.* (1992) stated that values of $Tu > 6000$ t km^{-2} a^{-1} (7th to 8th category) ‘are typical of basins developed mainly on Pliocene clayey bedrock and exposed to strong rill erosion and *calanco* type erosion’.

However, re-evaluation of catchment morphometry during the present study, using more detailed maps at the scale of 1:5000 produced by the Emilia-Romagna Carthographic Survey (CTR maps), revealed that many hydrographic basins in the $Tu > 6000$ t km^{-2} a^{-1} category actually lack typical *calanco* features.

It must, therefore, be concluded that the annual suspended sediment yield is insufficient to unequivocally identify catchments with *calanco* landforms, although an excessive annual yield of sediment is evidence of the presence of *calanchi*.

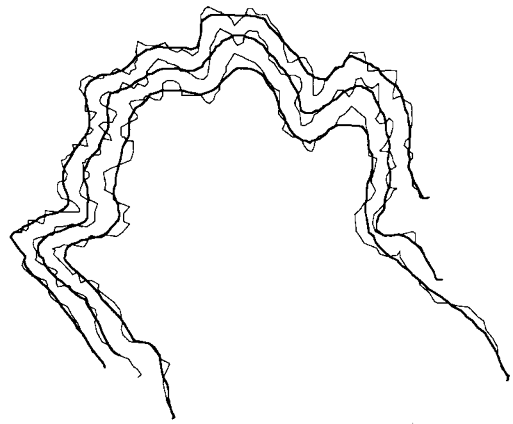


Figure 8. Three contours typical of *calanco* terrain before (thin lines) and after (heavy lines) smoothing

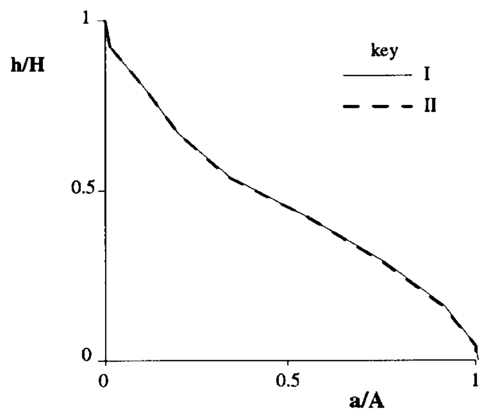


Figure 9. Comparison of hypsometric curves based on: I, original contours (hypsometric integral = 0·466); and II, smoothed contours (hypsometric integral = 0·473). Note that shape of curves and hypsometric integrals are unchanged by the smoothing process

CONTOUR CRENULATION: A POSSIBLE NEW PARAMETER TO AID IN IDENTIFYING *CALANCO* LANDFORMS

On topographic maps, areas of *calanchi* are characterized by very crenulated contour lines. This suggests that it may be possible to identify *calanco* landforms by comparing the actual shape of the contours with the shape of similar but smoothed lines representing the wider terrain of the basin.

To evaluate this suggestion, the original contour lines from a trial basin were first digitized in detail and then smoothed by means of an algorithm based on a moving average. The resulting contours should represent the land surface, but with badland features such as ridges, gullies and abrupt slopes filtered out. Figure 8 displays a typical example of some original contours and the corresponding, less crenulated lines produced by smoothing. The degree of crenulation due to badland features may be defined quantitatively by the ratio of the length of each original contour line *(LO)* to its filtered counterpart *(LF)*. This crenulation ratio (*LO*/*LF*) might provide a quantitative definition of the intensity of *calanco* landform features present in the landscape.

To check whether the filtered contours are still able to represent basin terrain faithfully, hypsometric curves obtained from the smoothed contour lines were compared to those for the original contours (Figure 9). The

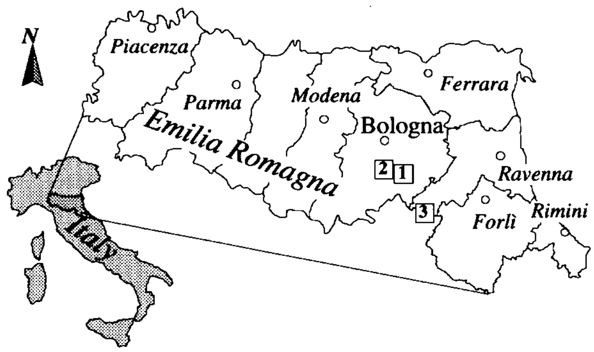


Figure 10. Location map for the three areas investigated in the field study

curves are almost identical, indicating that no problem arises in this respect, but also illustrating that catchment hypsometry is related to the general concavity of the landscape, rather than the detailed shape of the contours. This finding demonstrates why catchment hypsometry alone cannot define the presence or absence of *calanchi*.

FIELD AND MAP INVESTIGATIONS

Location of the investigated areas

Three areas, each of about 33 km^2, in the northern Apennines were investigated (Figure 10).

1. Idice-Quaderna (Ozzano Bologna). This area is located between the Zena-Idice and the Quaderna-Gaiana divides. The bedrock consists of Paleocene–Pliocene clayey sedimentary and tectonic melanges.
2. Monazzano basin (Pianoro, Bologna). Monazzano Creek is a left-bank tributary of Laurenzano Creek, in the Zena River basin. The bedrock consists of clay and sandstones of the Intrapenninic Basin (Pliocene).
3. Gamberaldi-Collecchio. This basin is located near Marradi (Firenze). It includes the hydrographic basins of Gamberaldi and Collecchio Creeks, which are left-bank tributaries of the Lamone River. The underlying bedrock is represented by the turbidites of the Marnoso-Arenacea Formation (Miocene).

These areas contain 67 hydrographic basins which are highly representative of the range of geological structures, vegetational types and erosional stages in the northern Apennines (Figures 11 and 12).

TESTING OF CONTOUR CRENULATION AS A NEW PARAMETER TO DEFINE *CALANCHI*

Four criteria were used in the field and map study to identify which of the 67 basins actually display *calanco* characteristics (Table I).

(1) *Field observations*: on the basis of fieldwork and subsequent discussions, a team of five experienced surveyors agreed that 24 basins have *calanco* characteristics.
(2) *Inspection of CTR maps*: examination of 1:5000 CTR maps revealed that 31 of the basins contain the symbol for *calanco* (symbol 6 in Figure 5).
(3) *Hypsometric analysis*: application of Strahler's analysis revealed that 17 basins have Family 1 hypsometric curves, indicative of *calanco* landforms.
(4) *Sediment yield analysis*: 42 cells were found to meet the criterion for *calanchi* that $Tu > 6000$ t km^{-2} a^{-1}.

Figure 11. Typical unvegetated *calanchi* on the ‘Chaotic complex’, Idice valley, Bologna

Figure 12. Typical *calanchi* with sparse vegetation on Pliocene clayey bedrock south of Bologna

Each basin was assessed using these criteria and, on the basis of this exercise, the basins were classified into five groups, according to the number and type of matching criteria.

The *LO*/*LF* ratio was also calculated for each basin. Values were found to range from 1·05 to 1·38. To investigate whether high values of the contour crenulation parameter are associated with the presence of *calanchi*, *LO*/*LF* values were compared to the five classes of catchment derived from the original four criteria (Table I). The resulting associations between *calanchi* criteria classes and *LO*/*LF* values are discussed in the following sections.

Table I. Results of field and map investigations for 67 study basins

METHODS: *In situ*	CTR	Hypso.	Tu	CELLS	LO/LF	CLASS
■	■	■	■	Mo4	1,23	1 (Mean 1,274 +/- 0,151)
■	■	■	■	Cl0	1,17	
■	■	■	■	As2	1,24	
■	■	■	■	As4	1,20	
■	■	■	■	As5	1,17	
■	■	■	■	Ca1	1,38	
■	■?	■	■	Tr0	1,27	
■	■	■	■	Ba1	1,37	
■	■	■	■	Ba3	1,37	
■	■	■	■	Ba4	1,38	
■	■?	■	■	Ri0	1,34	
■	■	■	■	Po0	1,24	
■	■	■	■	Mn1	1,25	
■		■	■	Bv0	1,22	
■?	■?		■	Ba2	1,19	2 (Mean 1,222 +/- 0,080)
■?	■		■	Fo0	1,21	
■?	■		■	No0	1,20	
■	■		■	Nc0	1,24	
■?	■?		■	La0	1,16	
■?	■?			As1	1,18	
■?	■		■	As6	1,25	
■	■		■	Sr0	1,30	
■?			■	Gt0	1,26	
■			■	Se0	1,23	
	■	■	■?	Mo5	1,10	3 (Mean 1,090 +/- 0,028)
	■	■	■	Mo6	1,07	
		■		Mo7	1,10	
	■			Mi0	1,17	4 (Mean 1,124 +/- 0,053)
	■		■	Mn3	1,12	
	■?			Mo1	1,09	
	■?		■	Mo2	1,11	
	■			Mo3	1,10	
	■		■	As3	1,11	
	■?		■	Cm0	1,13	
	■		■	Fa0	1,16	
				Mo8	1,10	5 (Mean 1,119 +/- 0,076)
				Be0	1,14	
			■	Gp0	1,11	
				Cs0	1,14	
			■	Ra0	1,12	
				As7	1,13	
				Ca2	1,15	
			■	Ca3	1,26	
				Bt0	1,14	
				Pi0	1,18	
			■	Fm1	1,11	
			■	Fm2	1,16	
			■	Fm3	1,09	
			■?	Fm4	1,07	
			■	Mp0	1,10	
				Ct0	1,13	
			■	Pz0	1,10	
				Bo1	1,05	
				Bo2	1,12	
			■	Fr0	1,13	
			■	Mn2	1,12	
			■?	Ga1	1,12	
				Ga2	1,07	
				Ga3	1,11	
				Ga4	1,05	
				Ga5	1,14	
				Ga6	1,12	
				Ga7	1,09	
				Co1	1,14	
				Co2	1,12	
				Co3	1,10	
				Co4	1,11	

Class 1

These basins meet all four of the criteria for definition as *calanchi*. They have *LO*/*LF* ratios ranging from 1·17 to 1·38 with a mean of 1·27 ± 0·15. Clearly, these basins have an abundance of *calanchi*. They display intensely crenulated hillslopes and *LO*/*LF* values are correspondingly high.

Class 2

These basins meet three out of four criteria for definition as *calanchi* (field observation of badlands, presence of *calanco* symbol on CTR maps and $Tu > 6000\ \mathrm{t\ km^{-2}\ a^{-1}}$). They have *LO*/*LF* ratios ranging from 1·16 to 1·30 with a mean of 1·22 ± 0·08. These basins commonly display intense crenulation of slopes that cut across bedding planes (faceslope bedding and transverse bedding), while hillsides formed in dipslope bedding are smoother in shape. Corresponding *LO*/*LF* values are, therefore, quite high, but are lower than for Class 1 basins.

Class 3

These basins meet two out of four criteria for definition as *calanchi* (hypsometric curve in Family 1 and either presence of *calanco* symbol on CTR maps, or $Tu > 6000\ \mathrm{t\ km^{-2}\ a^{-1}}$). *LO*/*LF* ratios range from 1·07 to 1·10 with a mean of 1·09 ± 0·03. *Calanchi* were not directly observed in any of the three basins in this class while, as the discussion presented earlier pointed out, concavity of the hypsometric curve is not necessarily due to the presence of *calanchi*. The topographic maps for Class 3 basins show little contour crenulation, resulting in very low *LO*/*LF* values that are consistent with the absence of *calanchi*.

Class 4

These basins meet only one or two of the criteria for definition as *calanchi* (*calanco* symbol on CTR maps and, in some cases, $Tu > 6000\ \mathrm{t\ km^{-2}\ a^{-1}}$). *LO/LF* ratios range from 1·09 to 1·17 with a mean of 1·12 ± 0·05. According to the field surveys no badlands or *calanco* landforms exist in these basins. In fact, direct observation reveals that the *calanco* symbols on CTR maps have been misapplied in that the features they represent are landslide scars and headwalls (cliffs) rather than *calanchi*. The low *LO/LF* ratio for Class 4 basins is, therefore, consistent with the absence of *calanchi*.

Class 5

These basins essentially meet none of the criteria for definition as *calanchi*, although in some cases the annual sediment load marginally exceeds the critical level. *LO/LF* ratios range from 1·05 to 1·18 with a mean of 1·12 ± 0·08. One outlier value, *LO*/*LF* = 1·26, may be attributed to the irregular shape of a small basin and has been ignored. The mean *LO/LF* ratio for Class 5 (which is identical to that for Class 4) is consistent with the absence of *calanchi*.

SUMMARY AND CONCLUSIONS

In an attempt to define the term *calanco*, five experienced surveyors visited 67 catchments formed in clayey bedrock along the northeast margin of the northern Apennines, Italy, and identified 24 catchments with *calanco* characteristics. To supplement field observations, three further criteria, based on morphological parameters commonly used in geomorphology, were selected to indicate the presence of *calanchi*. First, the relevant CTR maps were inspected for the presence of the *calanco* map symbol. Second, the hypsometric curve for basin topography was calculated. Third, it was established whether the annual sediment yield (*Tu*) exceeded a critical level of $6000\ \mathrm{t\ km^{-2}\ a^{-1}}$ identified by Ciccacci *et al.* (1992) as being associated with *calanchi*. Of the 24 catchments observed to display *calanco* characteristics, 14 met all four of these criteria.

The results of this investigation reveal limitations concerning the application of traditional approaches to morphological analysis in defining the presence of *calanchi*. For example, the *calanco* symbol on a CTR map does not necessarily indicate that badlands are present in the landscape because the symbol may also be used to indicate a landslide scarp or headwall generated by *non-calanco* processes. Similarly, the fact that the

Table II. Results of one-way analysis of variance (ANOVA) of *LO/LF* ratios for basins with and without *calanchi*

Source	df	Sum of Squares	Mean Squa...	F-Value	P-Value
LANDFORM	1	.276	.276	107.529	.0001
Residual	65	.167	.003		

Dependent: Calanchi_Similarity
Type III Sums of Squares

	Vs.	Diff.	Crit. diff.	
Calanchi	Non_Calanchi	.134	.026	S

S = Significantly different at this level.
Student-Newman-Keuls
Effect: LANDFORM
Dependent: Calanchi_Similarity
Significance level: .05

hypsometric curve for a basin falls into Family 1 (concave-upward hypsometric curves and low values of the hypsometric integral) characterizes the general morphology of the basin, but is unrepresentative of the detailed terrain features such as ridges, gullies and abrupt slopes associated with *calanchi* (see Figure 9). Finally, a high annual yield of suspended sediment (*Tu*) may be derived from active catchment erosion by *calanco* processes, but is equally likely to result from accelerated channel erosion due to instability in the drainage network.

In light of these limitations, it is proposed that contour crenulation, represented by *LO/LF*, offers an innovative, quantitative parameter with which to define the presence of *calanchi*. A one-way analysis of variance (ANOVA) (Table II) demonstrates a close association between direct observation of the presence and absence of *calanchi* in the field, and high and low values of *LO/LF*, respectively. It is suggested that utility and reliability of the *LO/LF* ratio as a predictor of calanchi should be further tested and validated independently through its application to basins in different parts of the Apennines.

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